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High-speed Clamping Mechanism of the CNC lathe with Compensation of Centrifugal Forces

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Abstract

The operation principles of both new and improved clamping mechanisms of the CNC lathe with the automatic no-reinstallation workpiece manipulation are described in this article. The theoretical analysis of power characteristics with the spindle in rotary and non-rotary modes has been carried out with the account of unbalanced chuck jaws' centrifugal forces. The efficiency of the new clamping mechanism at a higher spindle velocity has been justified.
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Keywords: CNC lathe; clamping mechanism; centrifugal forces; double clamp; clamp force; strengthening coefficient;

1. Introduction

One of the modern mechanical engineering development trends is a High Product Cutting with tool materials enabling High-Speed Cutting for up to 30 m/s blade processing at a high tool durability [2, 11].

High Product Cutting with large allowances and feeding is widely used at automotive, aerospace and machine tool engineering enterprises. High-Speed Cutting with low allowances and high velocity is promising for producing complex parts on milling machines, including those with parallel kinematics, and simple ones, mainly cylindrical, on CNC lathes [1].

For High-Speed Cutting on CNC lathes, it is necessary to create new structures for the clamping mechanisms and to search for new ways of clamping, e.g., high-speed tool holders with compensation of centrifugal forces [1-8].

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Earlier studies [3, 6] allowed identifying ways to improve the clamping mechanisms and the structure creation, which make up the objective of this work.

2. Improved clamping mechanism and its power characteristics

As the object of improvements, the German Patent No. 119 920 27 [10] and the Automatic CNC Lathe with hydraulic feeder and clamping bar have been chosen [4, 5, 9], in which a traditional lever-jaw chuck was used for clamping, and feeder rods were used for automatic manipulation of a workpiece with a hole (Fig. 1). Such manipulation objects could be flanges, glasses, cluster gears, etc.

Improved special clamping mechanism contains a spindle 9 (Fig. 1a) with a front end fixed coupling body 10 of the chuck with amplifying transfer lever members 11, tool slides 12 and cams 13 attached to them. The lever ends 11 through the pipe clamp 8 connected with the piston 7 of the rotary hydraulic cylinder 6 (rotary drive and oil supply are not shown). The expanding collet 15 is used for capturing the workpiece 14 from comb and its longitudinal movement, the expanding collet 15 screwed into the feed tube 5, which is mounted on the end with multiball bearing 4, covered by bracket at the outer ring, rigidly connected with the piston 2 rod 3 of the stationary supply hydraulic cylinder 1.

Hydraulic scheme of these mechanisms is described in this work [4]. After clamping the workpiece 14 in non-rotary spindle 9 mode, the rotating command is given by CNC, and the process of cutting begins (Fig. 1a). During cutting, the command is given to enter the expanding collet 15 (Fig. 1b) into workpiece hole. Due to the centrifugal force of unbalanced collet 15 petals, an additional clip is provided that partially offsets the loss of the radial clamping force due to centrifugal forces affecting the unbalanced cams 13 and sliders 12. After the workpiece 14 processing, the spindle is pulled up by CNC command. With stopped spindle, piston 7 moves to the right (Fig. 1c), spreading out slides 12 with cams 13 through the levers 11.

The chuck clamps workpiece 14, which on command along with the collet 15 and the tube 5 moves to the right from the hydraulic cylinder 1 piston 2 for unloading or transferring the workpiece to another processing position (not shown).

According to research [6], the amplification gain of cam-and-lever chuck in spindle non-rotary mode:

$$K_C = K_L \cdot K_{SL} = \frac{a_L}{b_L} \cdot \frac{1 - 2 \cdot f \cdot \dfrac{a}{l_S}}{1 + 2 \cdot f \cdot \dfrac{b}{l_S}} \tag{1}$$

where a_L , b_L – lever arms 11 at the inlet and the outlet; *a* –is the arm of force input relatively to the ram slide 12; b – is the arm of force output of the clamping side F_r at the contact point of the cam 13 and the workpiece 14; $l_S = \frac{2}{3} L$; L – is length of the ram slide 12; *f* – is the coefficient of friction.

On the other side

$$K_C = \frac{F_r}{F_a} \tag{2}$$

where F_a – is the front axial clamping force developed by hydraulic drive and equal to $F_a = p_3 \cdot S_3 \cdot \eta_3$ (p_3 – is a pressure in the hydraulic cylinder clamp 6; S_3 – is an area of the piston 7 in the cavity of the clamp; $\eta_3 = 0{,}85 - 0{,}9$ - Eff subject to losses due to friction in the moving surfaces, seals, etc.).

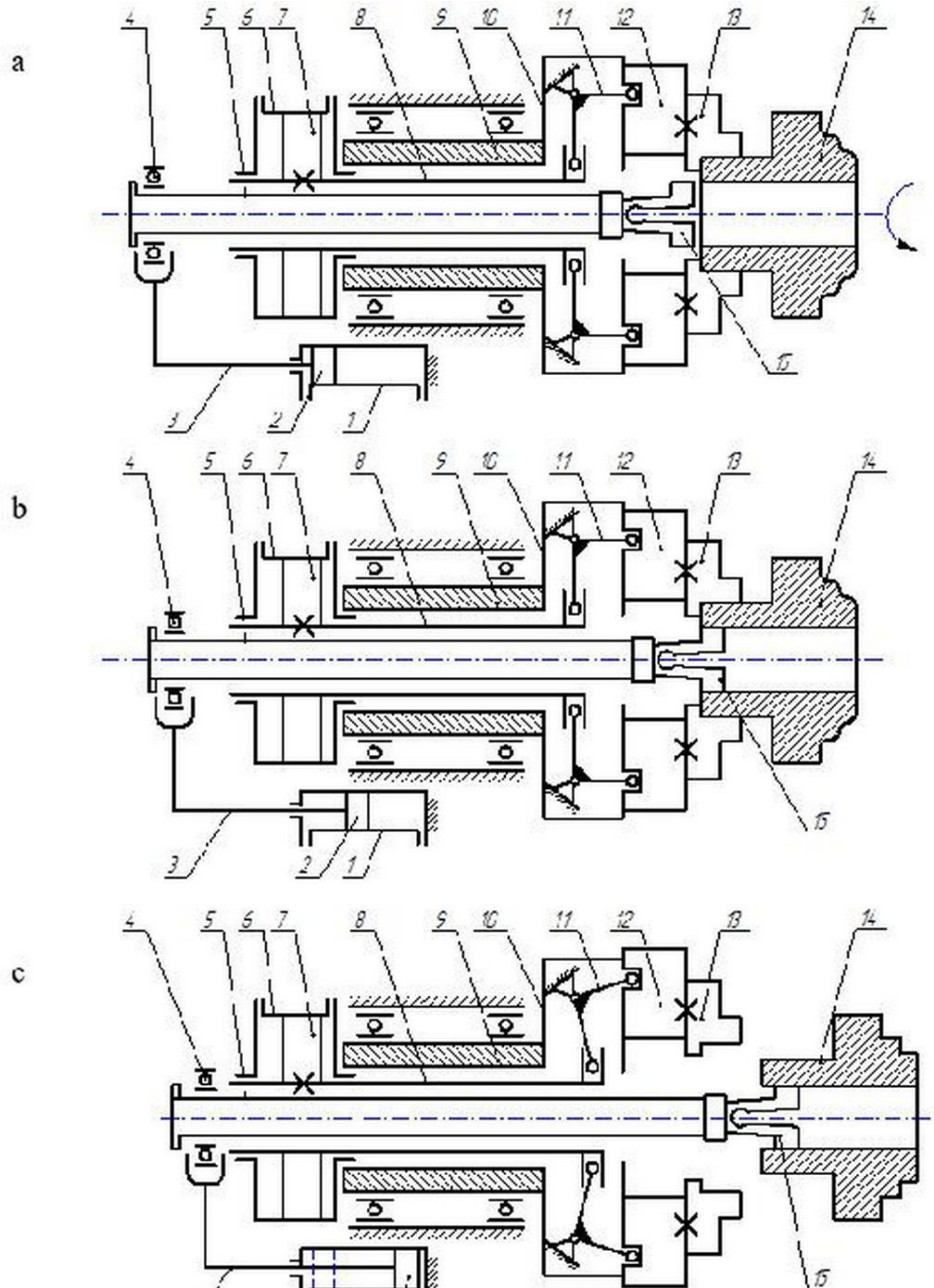

Fig.1. A special clamping mechanism for a sequential double clamp of the workpiece without reinstallation (the German Patent No. 119 920 27): (a) single clamp in the jaw chuck; (b) double clamp in jaw chuck and collet; (c) unary clamp in a draw-in attachment

As a result, the radial force of workpiece clamp is:

$$F_r = F_a \cdot K_C = p_3 \cdot S_3 \cdot \eta_3 \cdot \frac{a_L}{\text{в}_L} \cdot \frac{1 - 2 \cdot f \cdot \dfrac{a}{l_S}}{1 + 2 \cdot f \cdot \dfrac{b}{l_S}} \tag{3}$$

When the spindle rotates, centrifugal forces occur of unbalanced clamping elements (CE):

$$F_\omega = m_{CE} \cdot \omega^2 \cdot R_K , \tag{4}$$

where m_{CE} – is a CE weight; R_K – is a distance from the CE gravity centre to the axis of rotation; $\omega^2 = \frac{\pi \cdot n}{30}$ — is an angular rate speed of the ZP; n – is rotational speed, rpm.

Dynamic radial clamping force decreases (Fig. 2, curve A) and becomes plane:

$$F^0_{r\omega} = F_r - F_\omega . \tag{5}$$

Taking into account the friction forces F_T in the ram slide 12 and stiffness correlation α_c in the chucking system [6], the dynamic radial clamping force will make:

$$F^1_{r\omega} = F_r - (F_\omega - F_T) \cdot \alpha_c , \tag{6}$$

where $\alpha_c = \frac{C_{CO}}{C_C}$; C_{CO} – is reduced stiffness of clip object (CO) subject to a series connection of the CE contact stiffness – the cam 13, the CO – of the workpiece 14 and the rigidity of the CO body; C_C – is the stiffness of the chuck defined by hardness linkage with the open loop [2, 8].

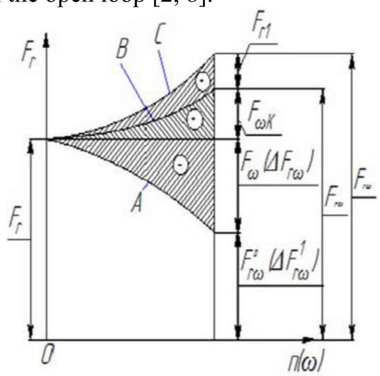

Fig.2. Dependency diagrams showing changes of the output radial clamping force by the CNC lathe spindle rotational velocity

When expander collet 15 enters the opening of the rotating workpiece 14 (Fig .3), the centrifugal force of unbalanced petals has place:

$$F^1_\omega = m_P \cdot \omega^2 \cdot R_0 . \tag{7}$$

Where m_p – is a weight of collet petal 15; R_0 – is the distance from the petal centre of gravity to the axis of rotation.

As a result, the dynamic radial clamping force increases and becomes plane (Fig. 2, curve B):

$$F_{r\omega}^{2} = F_r - (F_\omega - F_T)\cdot\alpha_c + F_\omega^{1} \quad (8)$$

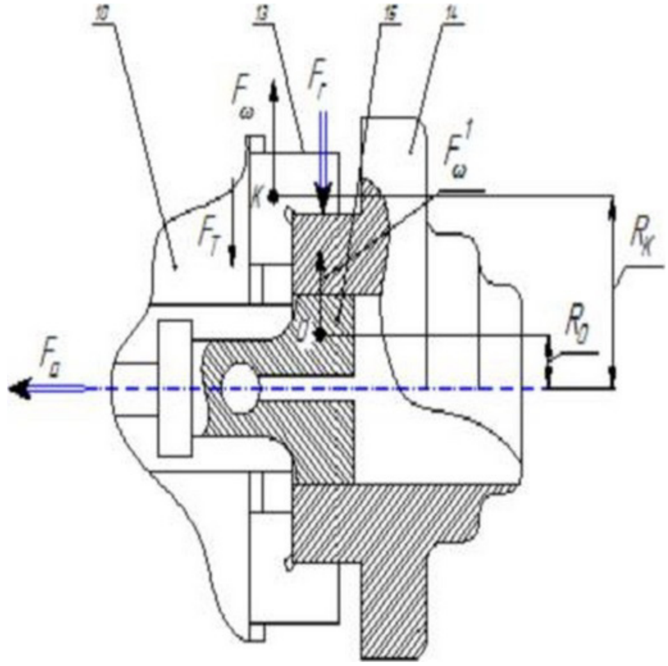

Fig.3. The forces acting on the special clamping mechanism (Fig. 1b) with double clip in the jaw chuck and collet expander

3. New clamping mechanism and its power characteristics

At high velocity, the loss in radial force caused by the unbalanced CE will exceed the equalizing due to the frictional force of the ram slide 12 and the centrifugal force of the collet 15 unbalanced petals, in other words

$$\Delta F_{r\omega} = F_\omega\cdot\alpha_c > F_T\cdot\alpha_c + F_\omega^{1} \quad (9)$$

it means that $F_{r\omega} < F_r$.

This required a new approach to the creation of a high-speed clamping mechanism under the existing lever-jaw chuck, hydraulic drive clamp and feed [7].

Comparing with the clamping mechanism showed in Fig .1, a tapered wedge 16 was put into the new mechanism within the tapered bore expander collet 15 (Fig. 4a); this wedge connected with a rod 17 through the adjustment nut 22 with ball compensator of centrifugal force (Fig. 4b) attached to the feed pipe 5 in the form of a hollow body 18. In the middle of this body 18, on the one side, there are movable sleeve 19 and the cup 23 separated by a spring 20, creating a gap Δ, and on the other side, there are balls 21.

Clamping mechanism works in the following manner. The workpiece 14 is set to the opening of the collet holder 16 with the petals 15 in the clamping jaws 13, whereupon the right-hand chamber of the hydraulic cylinder 6 is supplied with oil under pressure p_3, and the piston 7 with the clamp pipe 8 moves to the left, bringing sliders 12 with cams 13 through levers 11. From the axial force F_a the radial clamping force F_r is created, defined by the formula (3).

When the spindle starts rotating, the supply pipe 5 and the body 18 start rotating too through collet holder 16. Affected by the centrifugal force, the balls 21 diverge trying to press to the inner surface of the housing 18 and moving the sleeve 19 to the left.

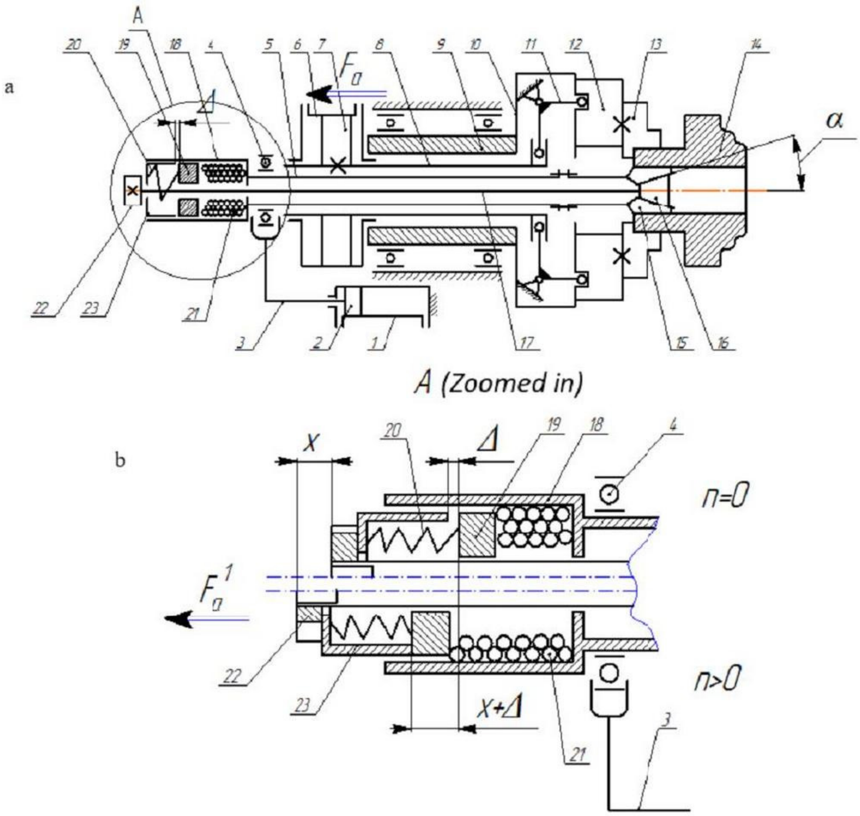

Fig.4. CNC lathe high-speed clamping mechanism with compensation of centrifugal forces: a - spindle line; b - ball compensator of centrifugal forces

The gap Δ adjusts, the spring 20 compresses and the stem 17 with tapered wedge 16 moves to the left through the nut 22 (preload of the elastic system by a quantity of X).

The centrifugal force caused by the balls 21 is following:

$$F_{\omega}^{2} = z_b \cdot m_b \cdot \omega^2 \cdot R_B , \tag{10}$$

where m_b – is the ball mass; z_b – is balls quantity; R_B – is a distance from the centre of balls gravity to the axis of rotation.

Under of elastic chain preload from the balls 21 through the sleeve 19, the cup 23, the nut 22 and the spindle 17 to the collet holder 16-15, an additional axial force appears:

$$F_{a1} = X \cdot C_y \approx X \cdot E \cdot \frac{S_{ST}}{L_{ST}} , \tag{11}$$

where C_y – is the stiffness of the elastic bead chain 21 – collet chuck 16-15 as a serial connection of the elastic units, among which the stem 17 (length is L_{ST}) is the most malleable; S_{ST} – is cross-section area of the stem.

From axial force F_{a1}, an additional radial clamping force takes place:

$$F_{r1} = F_{a1} \cdot K_C = F_{a1} \cdot tg(\alpha + \varphi)\,, \tag{12}$$

where K_C – is an intensifying factor of collet holder; α – is a half angle of the cone expander collet 15; φ – is friction angle in conjunction of collet 15 – wedge 16.

The total dynamic radial clamping force in a new clamping mechanism increases to:

$$F_{r\omega}^3 = F_r - (F_\omega - F_T) \cdot \alpha_c + F_\omega^1 + F_{r1}\,. \tag{13}$$

As a result, the stabilization is possible or even the increase of the radial clamping force, i.e.: $F_{r\omega} \geq F_r$.

The new clamping mechanism (Fig. 5), as on Fig. 1, allows an automatic CO manipulation in accordance with CNC commands.

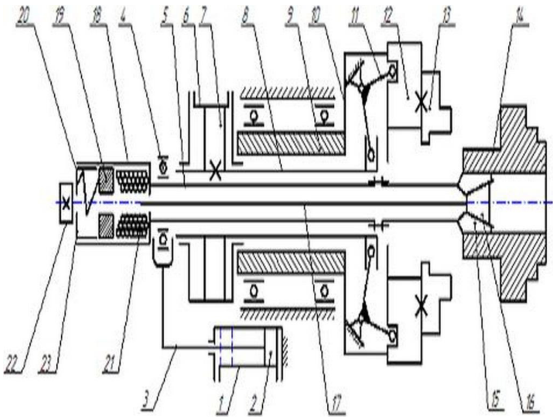

Fig.5. High-speed clamping mechanism with automatic workpiece manipulation

4. Conclusions

Preliminary comparative theoretical research of both improved and new clamping mechanisms for CNC lathes has shown that according to their power characteristics they can be used for High-Speed Cutting and High Product Cutting. The most effective is a clamping mechanism with a ball compensator of centrifugal forces in case of a holed workpiece double clamp.

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